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THE EFFECTS OF A CM EPS BATTERY FAILURE DURING LOAD SHARING AND OF A FUEL CELL FAILURE AT LAUNCH FOR AS-501

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PROJECT APOLLO

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FIGURES

THE EFFECTS OF A CM EPS BATTERY FAILURE DURING LOAD SHARING AND OF A FUEL CELL FAILURE AT LAUNCH FOR AS-501

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SUMMARY

This report analyzes the effects of a failure during load sharing of battery B of the CSM electrical power system (EPS) at the end of the first SPS burn during the AS-501 mission. Such a failure would not affect the mission until CM/SM separation prior to entry because power is available from the fuel cells on the SM. However, without the SM fuel cells after separation, the failure of battery B would reduce the CM bus voltages too much to reliably operate the electronics required for a G&N controlled reentry.

If a single fuel cell failure occurs at launch, there will be sufficient power in the two remaining cells to continue the mission. If, in addition to the fuel cell failure, battery B fails at the end of the first SPS burn, the effect on reentry is essentially the same as for the failure of battery B only.

If initial charge status on the batteries were increased from 40 amp-hr to 50 amp-hr, there would be sufficient energy in the one remaining battery for reentry, but bus voltages would still be too low to guarantee a controlled reentry.

INTRODUCTION AND ASSUMPTIONS

This study was made to determine the capability of the spacecraft to perform reentry following the failure of the CSM-EPS battery B during the first SPS burn. (Failure of battery A would present an identical problem.) The analysis was performed using a computer simulation of the CSM EPS. This program (AESOP-II) was used to produce the consumables budget for the nominal AS-501 mission (ref. 1). Reference 2 established the guidelines for this study. The following assumptions were valid for this study.

1. The failure of battery B during load sharing removes power from battery bus B, which provides the power that controls the load sharing of battery bus B with CM bus B, and battery C with CM bus A. Therefore, failure of battery B would not permit the removal of battery C from load sharing with CM bus A.

2. The initial charge of each battery is 40 amp-hr.

3. The prelaunch mission requirements reduced the charge of batteries A and B to 27.31 amp-hr and battery C to 35.80 amp-hr at launch.

4. The timeline used for this study was the same as that used in the consumables analysis for the nominal AS-501 mission (ref. 1).

5. Battery B failed at the end of the first SPS burn.

6. Inverter 3 is switched to CM bus A at separation to pick up the alternating-current power load dropped by inverter 2 on CM bus B. (No power is supplied to CM bus B after separation.)

7. The batteries were assumed to be depleted when the charge status became 0 amp-hr.

RESULTS

Figure 1 presents a simplified picture of the battery-bus-motor switch configuration. Only one motor switch is shown; however, there is a similar switch operating off battery bus A. The failure of battery B during the first SPS burn causes battery C to be left on CM bus A in load sharing with the fuel cells.

The mission power profile is nominal until the battery B failure occurs. This can be observed by examining the battery current profile shown in figure 2. At the end of the first SPS burn, during load sharing a battery B failure was simulated. This left battery C on the CM bus A for the remainder of the mission since power had been removed from battery bus B which supplies power to the motor switch controlling removal of battery C from load sharing. The mission time at which this occurs was 3 hr 29 min. Figure 3 presents the battery voltage as a function of the contingency timeline. The significant events are noted on the curves. Figure 4 describes the battery A current profile for reentry. Figure 5 shows the charge status of battery A as the mission progresses.

It should be noted that the charge status of battery A becomes negative at about 1.6 minutes prior to splashdown, indicating depletion at 0 amp-hr.

At the point at which the charge status of battery C becomes 0 amp-hr, it is turned off to simulate depletion. This occurs at 6 hr 50 min into the mission. The fuel cells then carry the full power load for the remainder of the mission until CM-SM separation except during the second SPS burn during which battery A is load sharing.

At the second SPS burn, battery A, the only one remaining, is again switched on the line in load sharing. Figure 6 presents a profile of a single battery in load sharing during a primary ΔV maneuver. These curves show that the load on battery A is quite heavy during the burn.

Of prime importance, however, are the battery and main bus voltages. Figures 7 and 8(a) show their respective profiles. Figure 8(b) depicts CM bus A voltage for the time from separation to splashdown. At separation the peak load on battery A lowers the CM bus voltage to approximately 25.2 volts. This voltage is low enough to cause CM electrical system failures.

Figures 9 and 10 present fuel cell voltage and current profiles for the contingency situation. These profiles are nominal except for the period in which battery C remains on the line in load sharing.

As an alternate procedure for this contingency, an additional study was made in which batteries A and C were both left in load sharing following the failure of battery B. Using this configuration, both batteries A and C are depleted prior to CM/SM separation (6 hr 41 min and 7 hr 41 min, respectively). Therefore, no spacecraft battery power is available after separation to perform reentry.

CONCLUSIONS

Reentry with one 40 amp-hr battery cannot be accomplished because the CM bus voltage is too low to reliably operate some of the electronics required for a G&N reentry. If 50 amp-hr batteries are used, battery C would still be depleted before CM/SM separation, leaving battery A to perform reentry. Battery A would retain sufficient energy for reentry; however, the low bus voltage problem would not be changed by increasing the charge to 50 amp-hr.

It should be pointed out that the loss of battery C is not too serious since both batteries A and B can still be switched on or off the line and can be used for reentry. This would allow the CM bus voltages to be kept up to a tolerable level for reentry.

A single fuel cell failure at launch will not affect the primary mission, because there will be sufficient power in the two remaining fuel cells to continue the mission. The failure of battery B in addition to the fuel cell failure would have essentially the same effects as the failure of only battery B. That is, the loss of both battery B and a fuel cell is no more detrimental to mission success than the single failure of battery B.

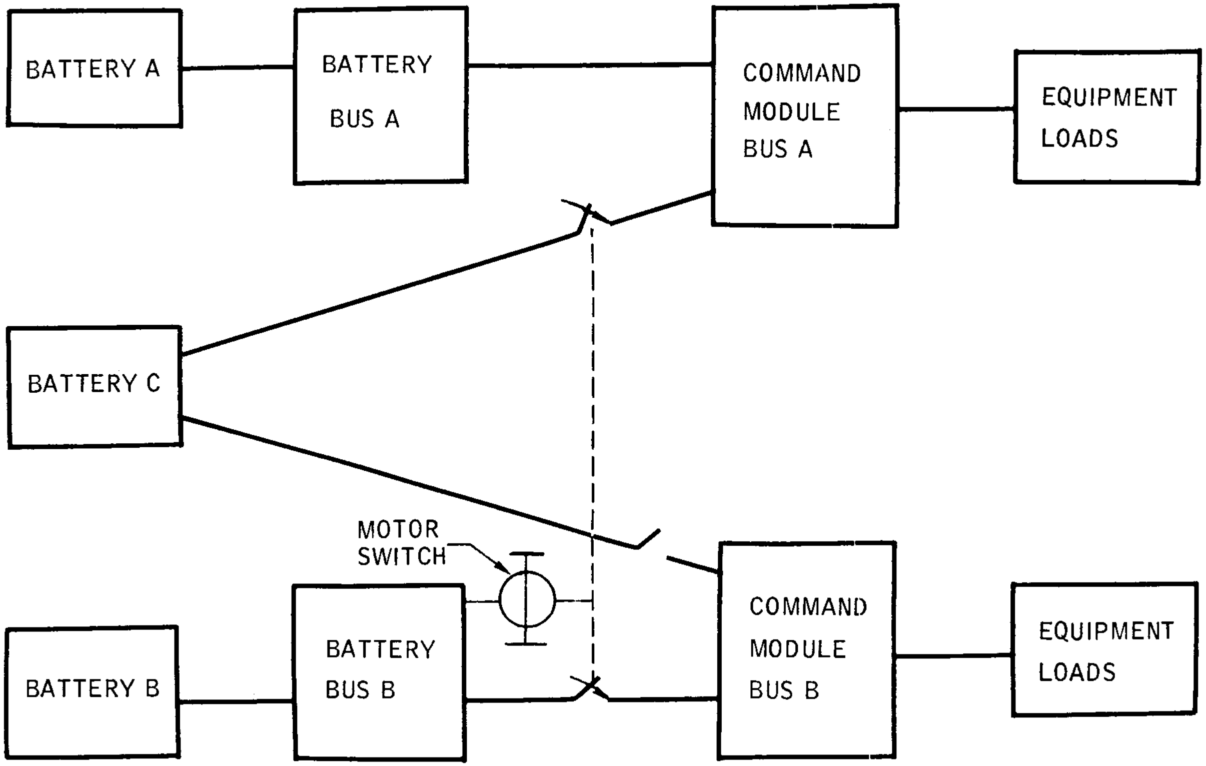

Figure 1.- Command module battery power distribution configuration.

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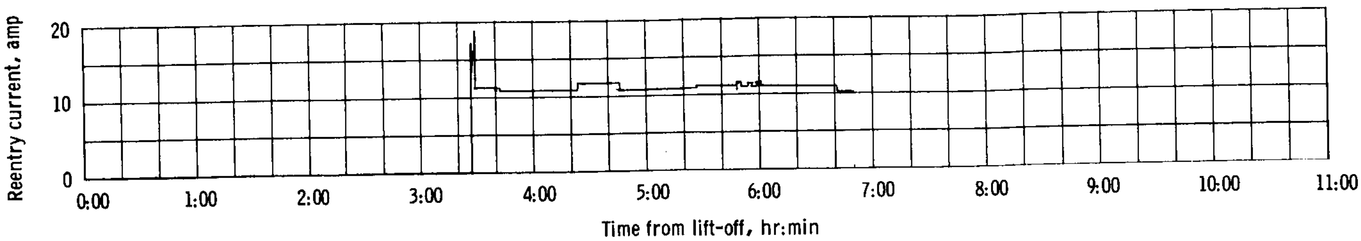
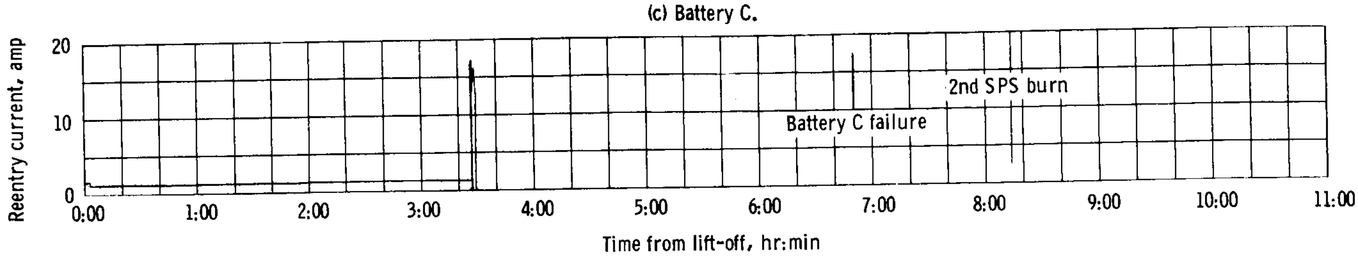
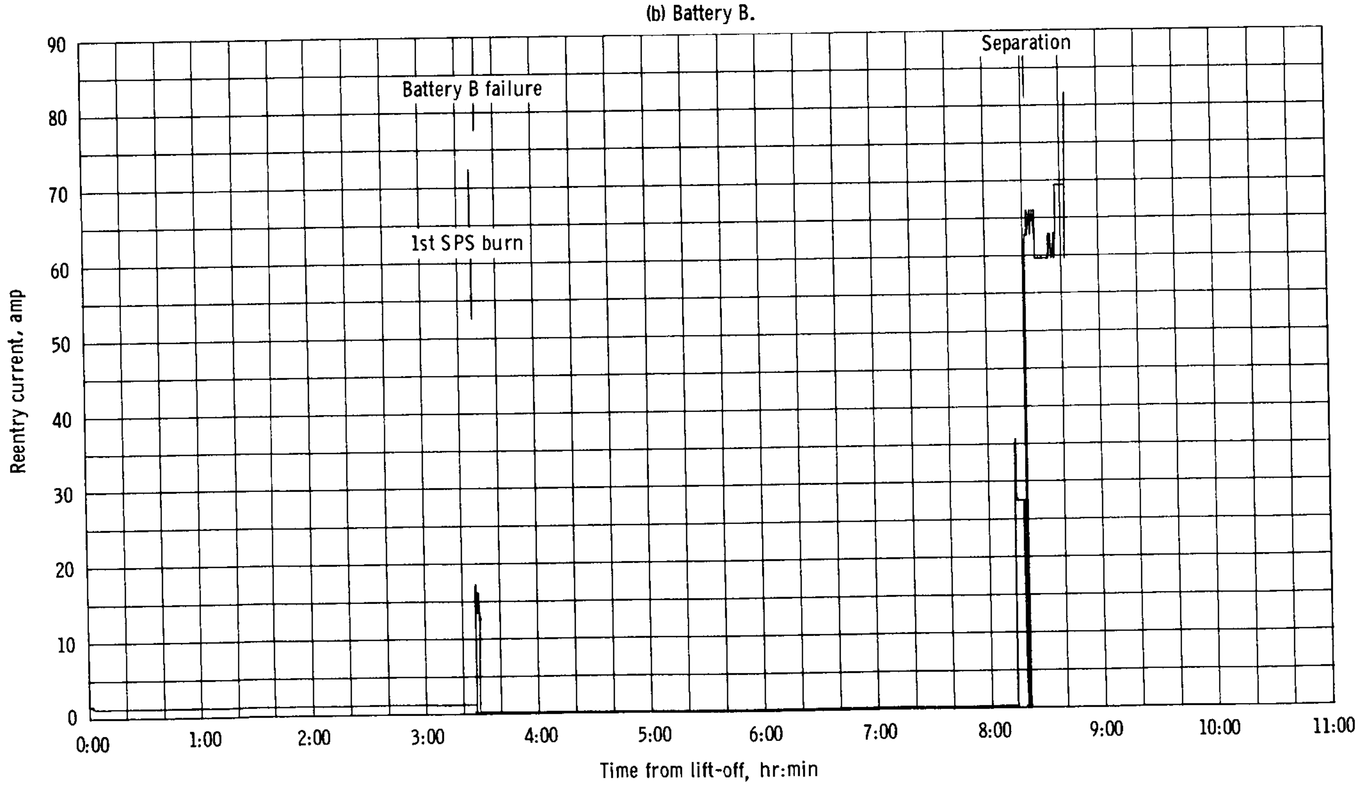


(c) Battery C.



(b) Battery B.



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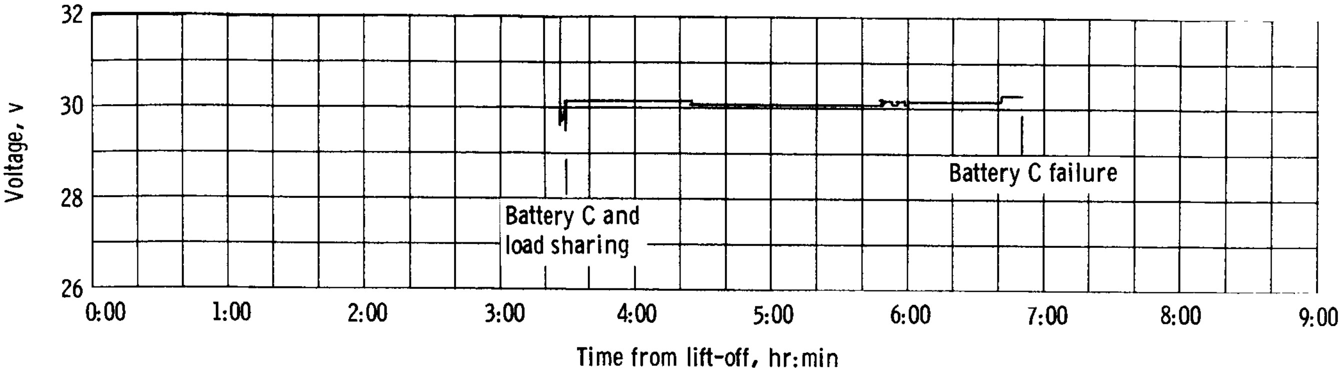
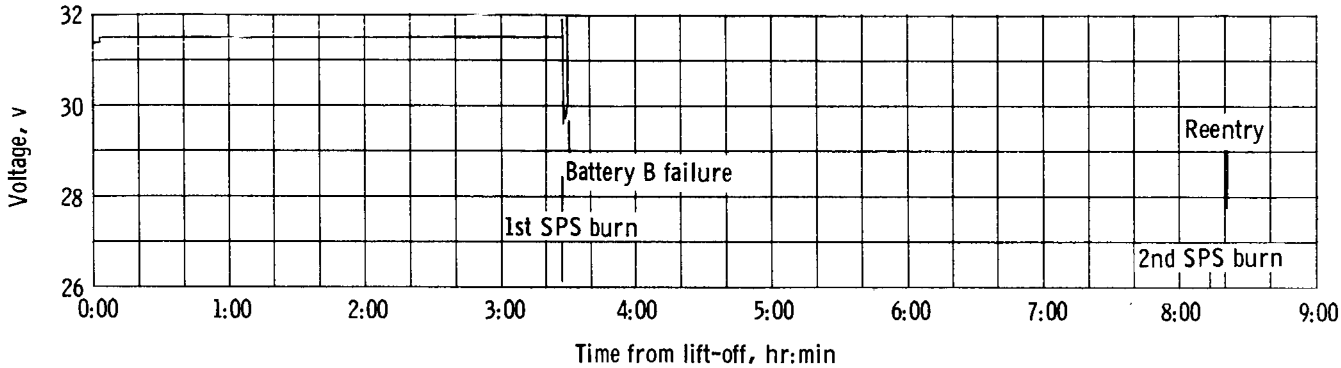
(a) Battery A.

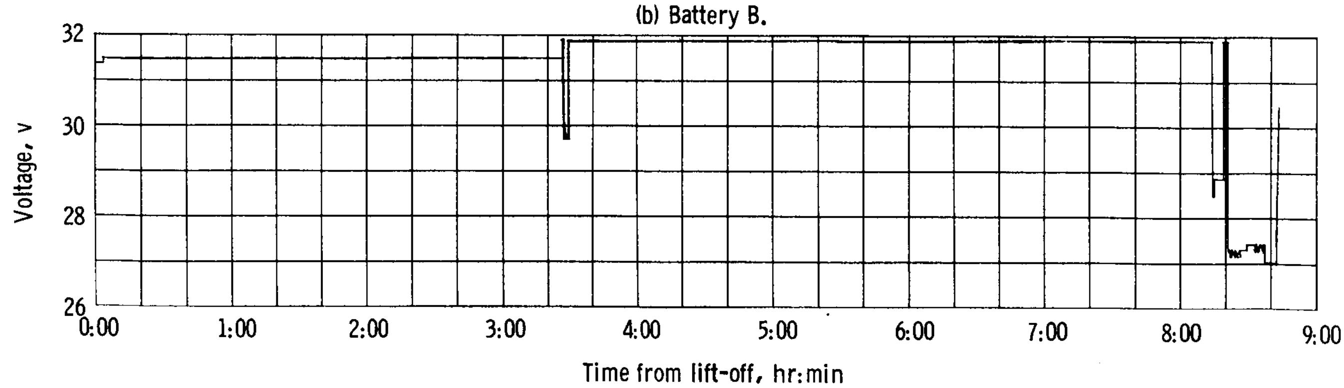
Figure 2. - Command module battery current versus time.



(c) Battery C.



(b) Battery B.



(a) Battery A.

Figure 3.- Command module battery voltage versus time.

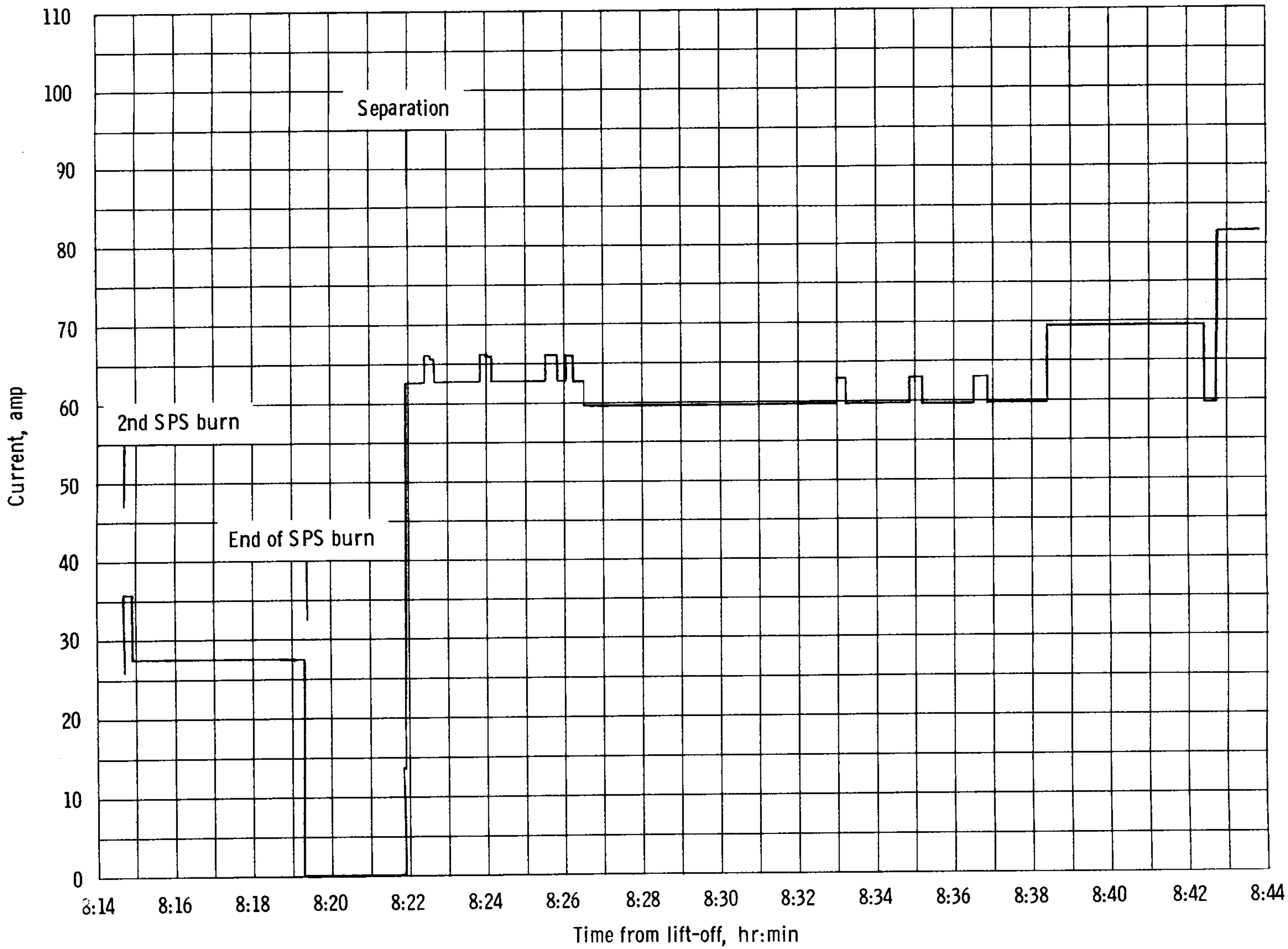


Figure 4. - Battery A current versus time during reentry phase.

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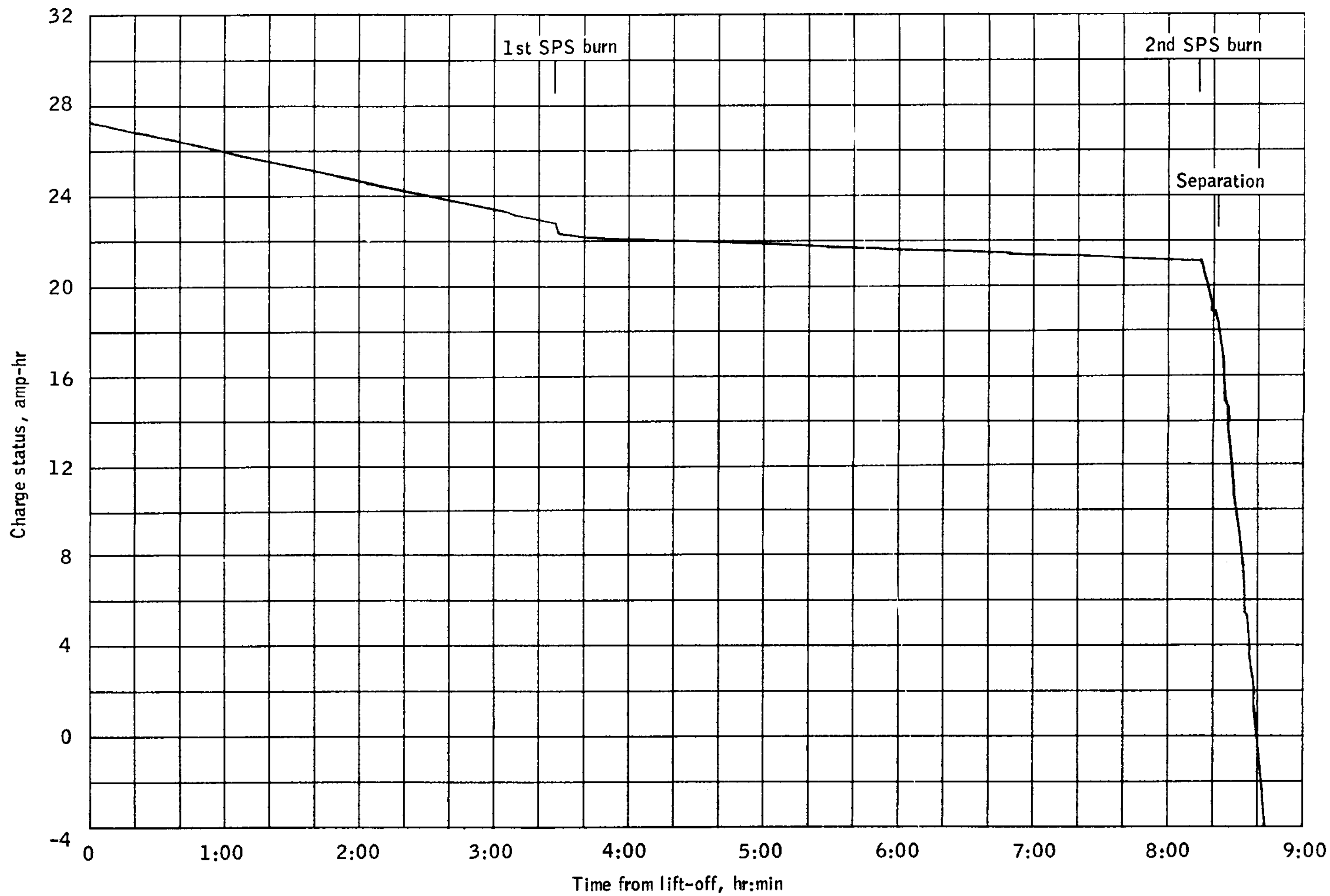

Figure 5.- Battery A charge status versus time.

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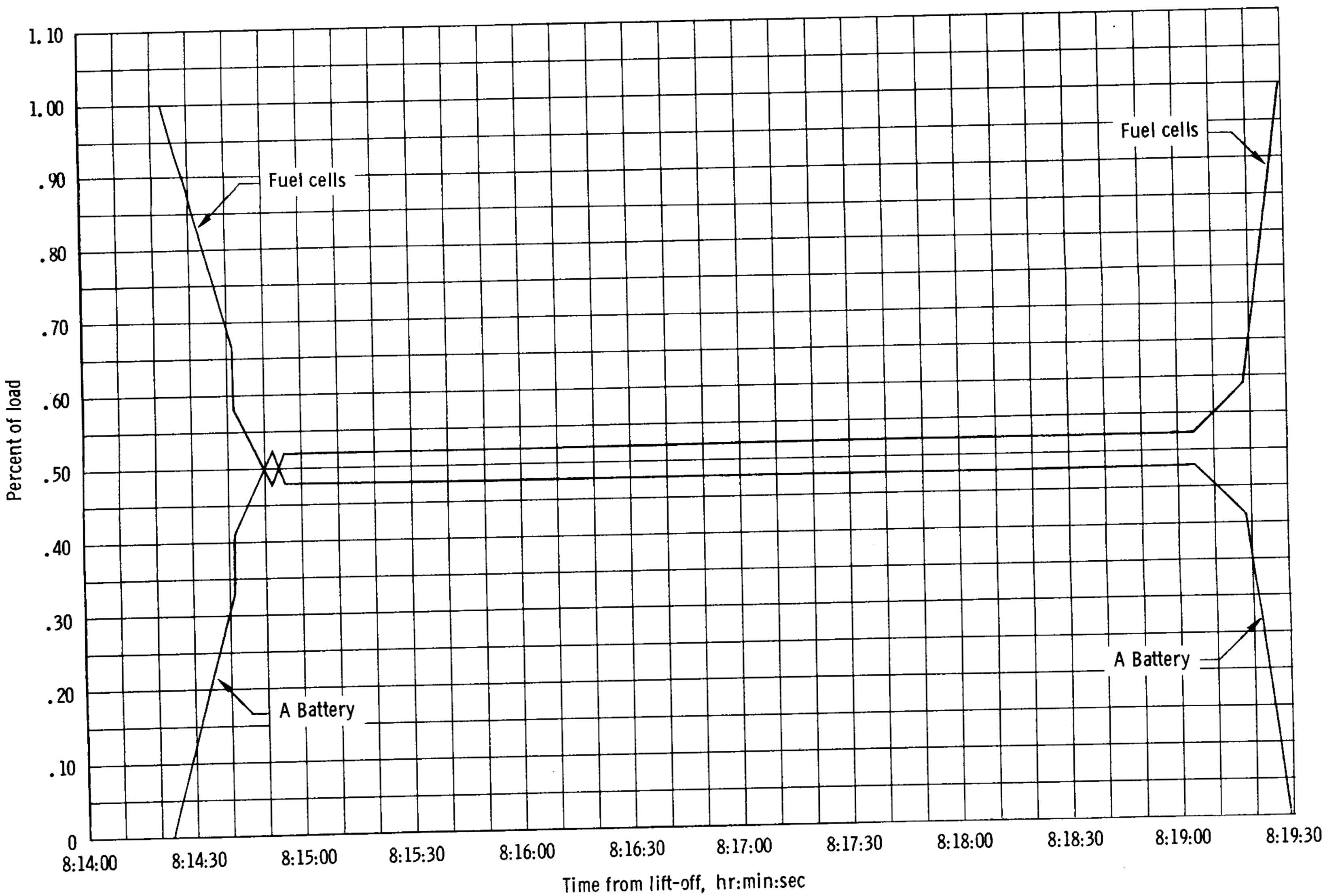

Figure 6. - Load sharing versus time for second SPS burn.

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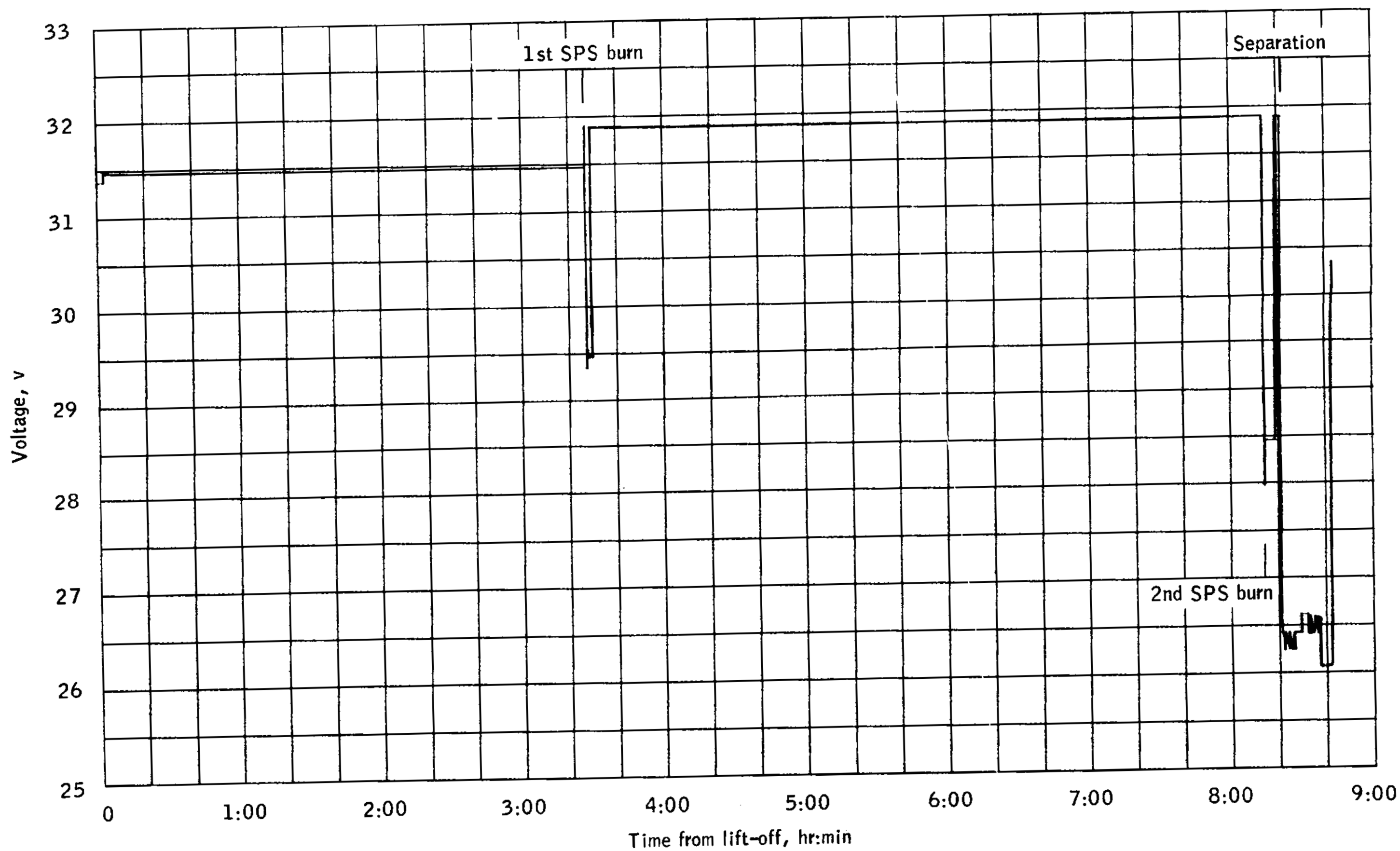

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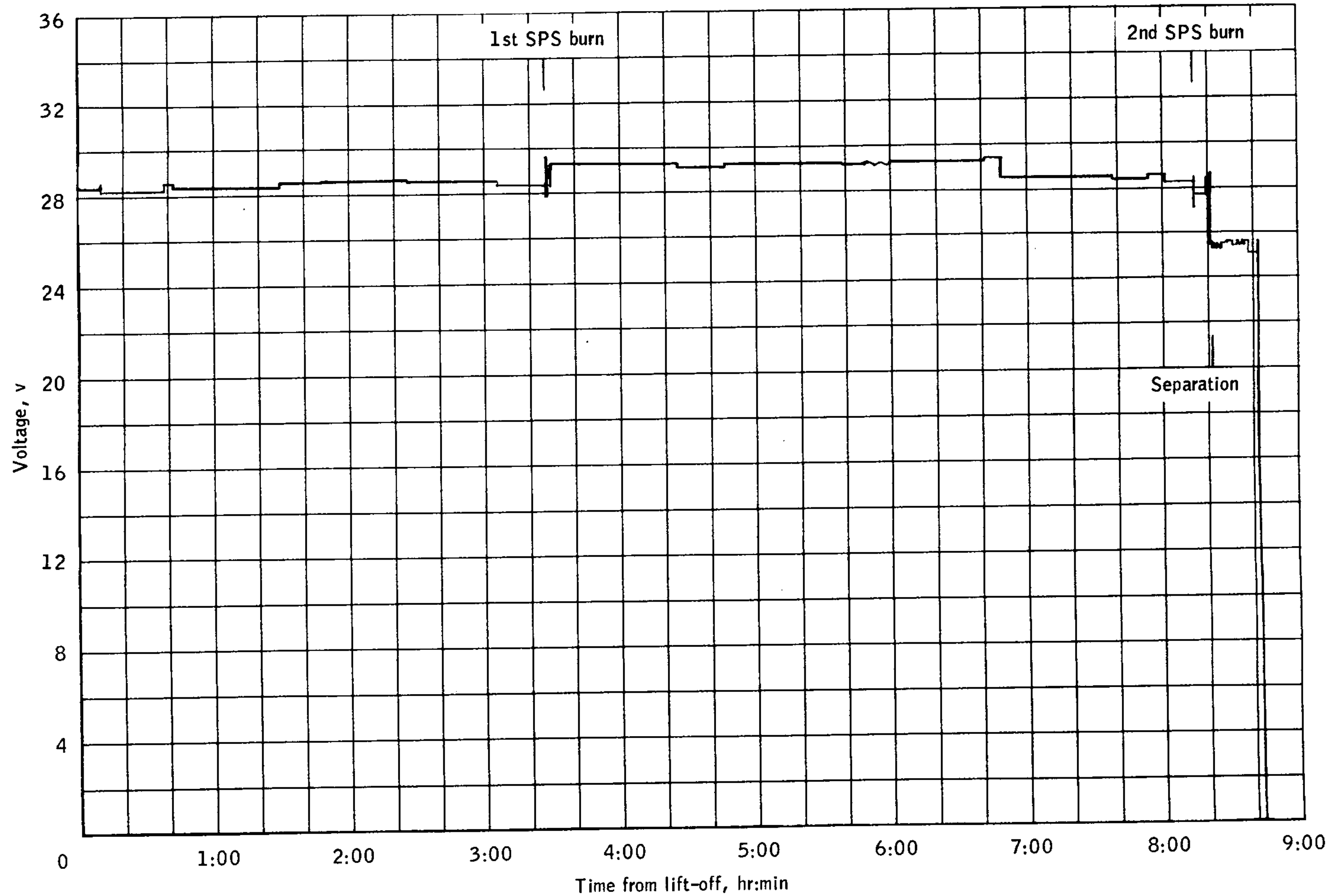
Figure 7.- Battery bus A voltage versus time.



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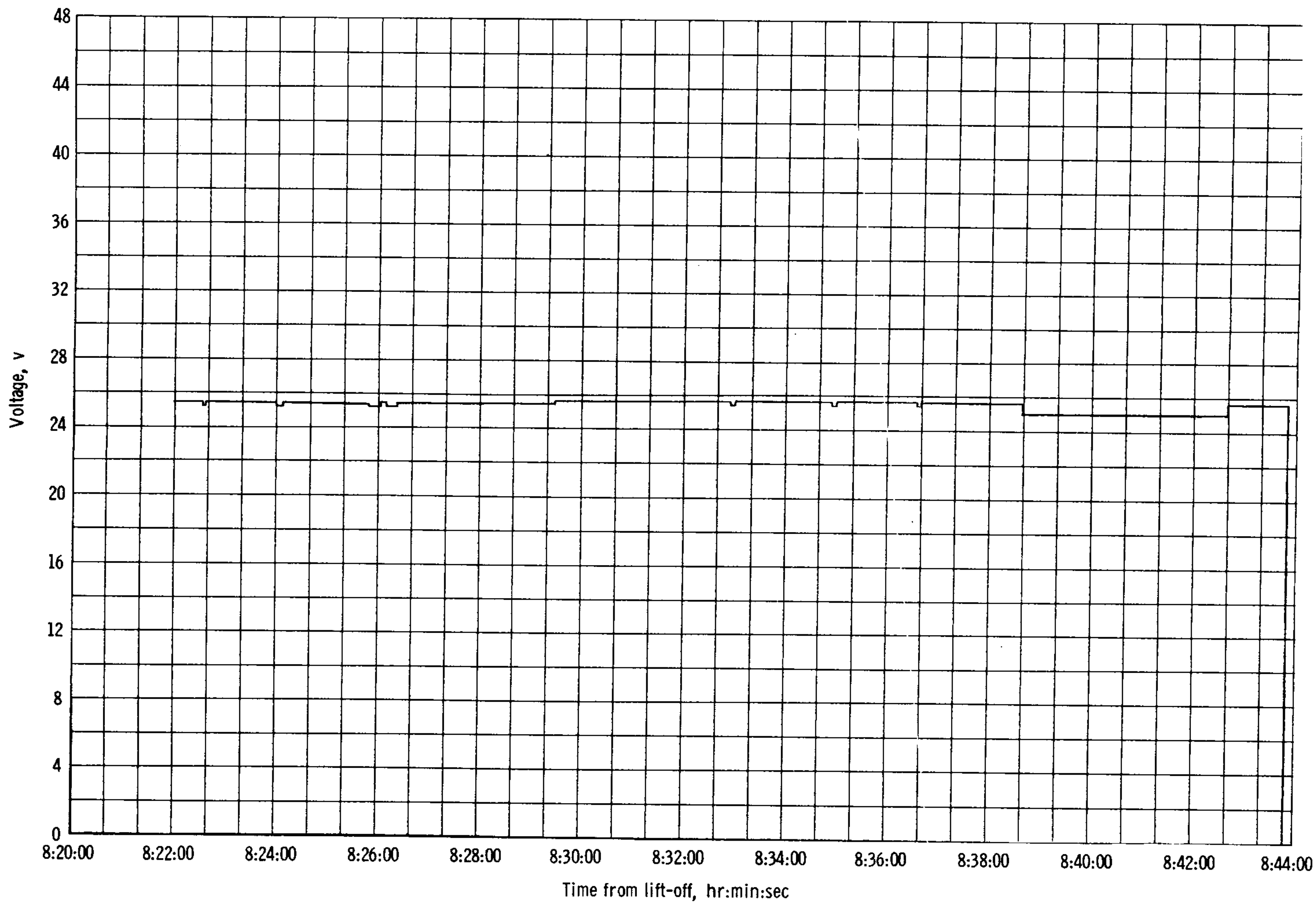
(a) Lift-off to splashdown.

Figure 8.- Command module bus A voltage versus time.



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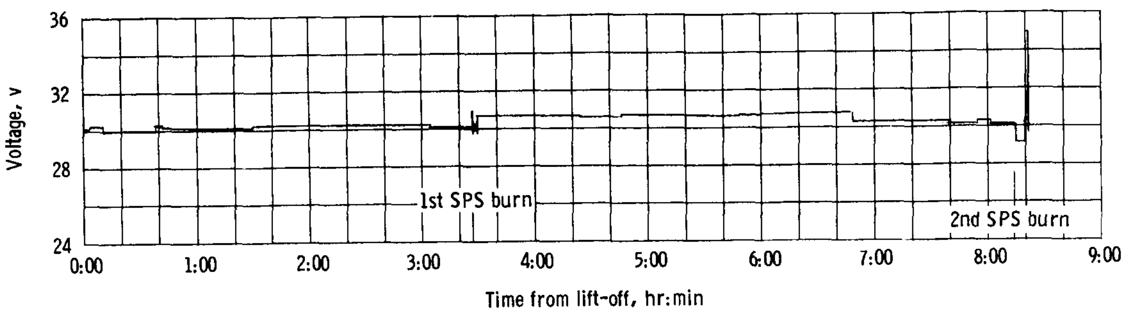
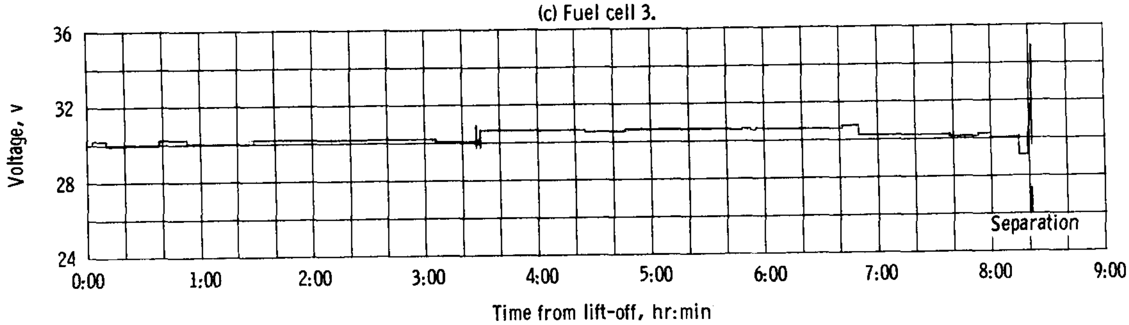
(b) CM-SM separation to splashdown.

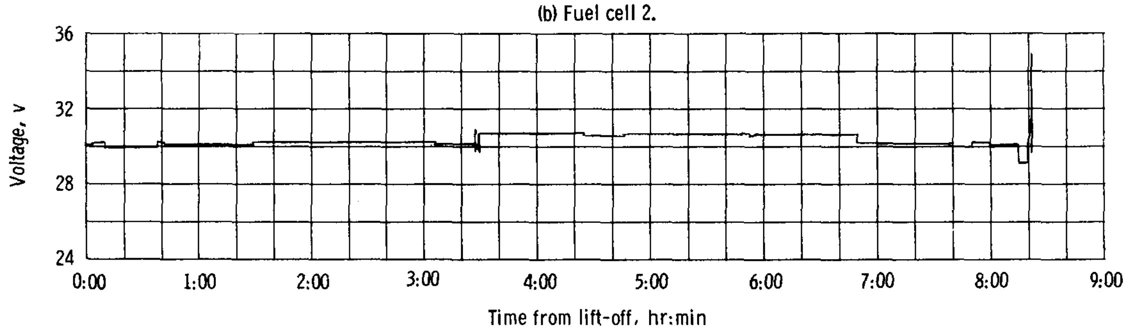
Figure 8. - Concluded.



(c) Fuel cell 3.



(b) Fuel cell 2.



(a) Fuel cell 1.

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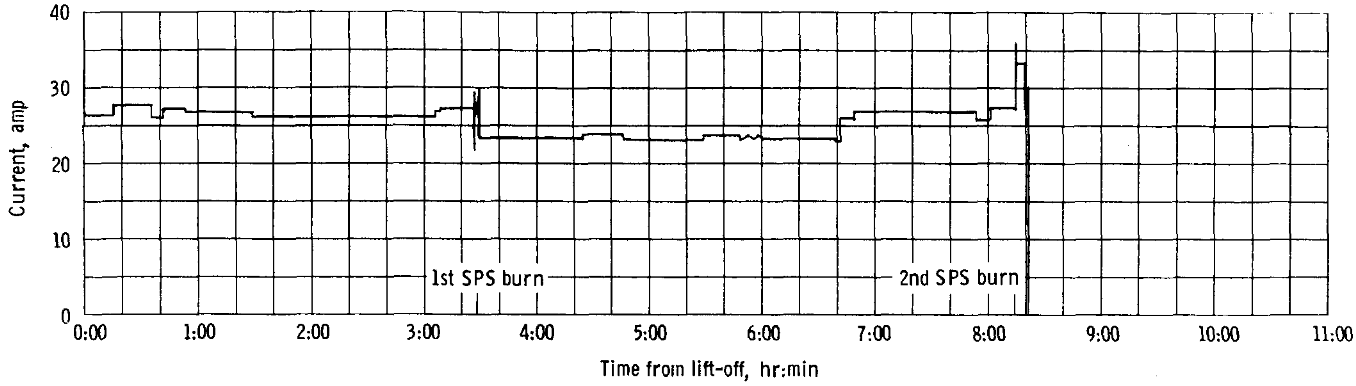
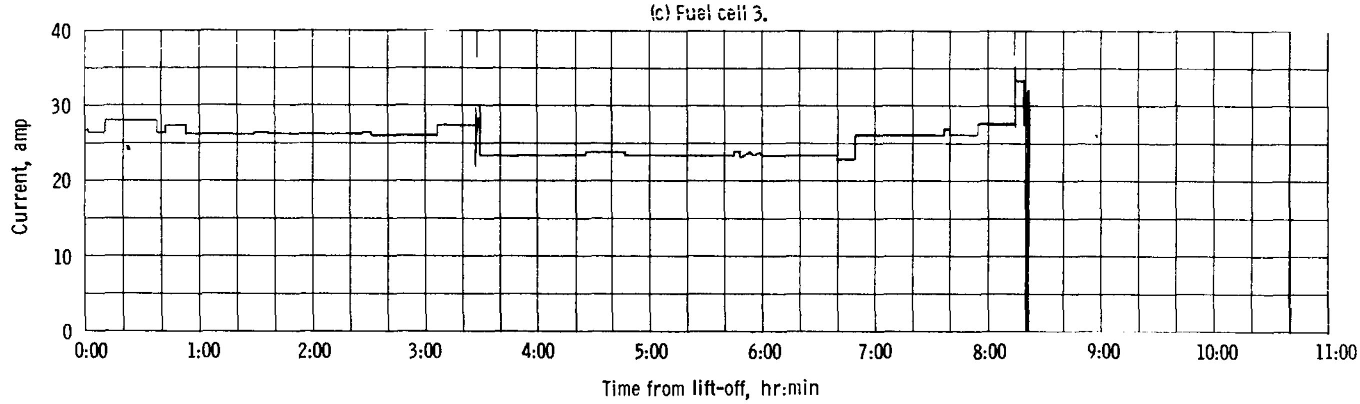
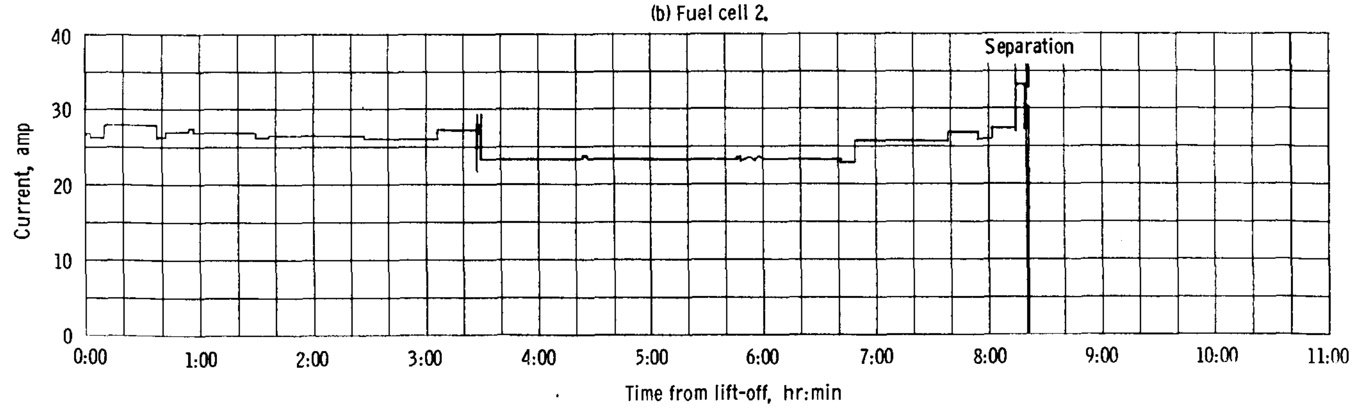
Figure 9. - Fuel cell voltage versus time.



(c) Fuel cell 3.



(b) Fuel cell 2.



(a) Fuel cell 1.

Figure 10. - Fuel cell current versus time.

REFERENCES

1. Brown, Robert and Snygg, Arnold: Apollo Mission AS-501/017 Consumables Analysis. MSC Internal Note 67-FM-126, September 1, 1967.

2. Flight Control Division: Request for AS-501 EPS Contingency Study. Flight Control Division Memorandum, August 14, 1967.